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<p>(21) International Application Number: PCT/AU94/00646</p> <p>(22) International Filing Date: 24 October 1994 (24.10.94)</p> <p>(30) Priority Data:</p> <table> <tr> <td>PM 2012</td> <td>26 October 1993 (26.10.93)</td> <td>AU</td> </tr> <tr> <td>PM 4092</td> <td>25 February 1994 (25.02.94)</td> <td>AU</td> </tr> <tr> <td>PM 6044</td> <td>1 June 1994 (01.06.94)</td> <td>AU</td> </tr> </table> <p>(71) Applicant (<i>for all designated States except US</i>): KINETIC LIMITED [AU/AU]; 9 Clarke Street, Dunsborough, W.A. 6281 (AU).</p> <p>(72) Inventors; and</p> <p>(75) Inventors/Applicants (<i>for US only</i>): HEYRING, Christopher, Brian [AU/AU]; 11 Fern Road, Eagle Bay, W.A. 6281 (AU). HARRIES, Bryan, John [AU/AU]; 71 Peppermint Drive, Dunsborough, W.A. 6281 (AU). DIMMOCK, Bradley, John [AU/AU]; 3 Marshall Street, Dunsborough, W.A. 6281 (AU). HESLEWOOD, Raymond, Charles [AU/AU]; 13 Alpha Road, Busselton, W.A. 6280 (AU).</p> <p>(74) Agent: WATERMARK PATENT & TRADEMARK ATTORNEYS; 'Durack Centre', 4th Floor, 263 Adelaide Terrace, East Perth, W.A. 6004 (AU).</p>		PM 2012	26 October 1993 (26.10.93)	AU	PM 4092	25 February 1994 (25.02.94)	AU	PM 6044	1 June 1994 (01.06.94)	AU	<p>(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SI, SK, TJ, TT, UA, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ).</p> <p>Published <i>With international search report.</i></p>	
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<p>(54) Title: VEHICLE SUSPENSION SYSTEM</p> <p>(57) Abstract</p> <p>A suspension system for a wheeled vehicle including a double acting ram (13, 14, 17, 18) connecting respective wheels to the vehicle body. Each ram has an upper and a lower chamber, a conduit (8, 8a, 10, 10a) individually connecting the upper chamber of a respective ram with the lower chamber of the diagonally opposite ram. Load unit (40) is connected between conduits (8, 8a, 10, 10a) to substantially equalise pressure therebetween and consequently loadings between wheels. A sensor (364) indicates the height of each pair of diagonally opposite wheels. A control unit (68) receives signals from wheel height sensors (360, 361, 362, 363) and sensor (364) to control valves (67) which adjust the quantity of fluid in the rams and the conduits to facilitate optimum position and load equalisation for each of the wheels.</p>												

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VEHICLE SUSPENSION SYSTEM

This invention relates to improvements in the suspension system for a vehicle, and is specifically related to controlling the disposition of the vehicle body relative to the vehicle wheels when the vehicle is subject to 5 load distribution variation.

In recent times there has been a trend towards resilient sprung suspension systems incorporating variable damping and spring rates in an attempt to improve vehicle stability and reduce movement of the vehicle body relative to the surface being traversed. Some more advanced suspension 10 systems, commonly referred to as active and semi-active suspensions, incorporate a number of electronic sensors which monitor information such as vertical wheel travel and body roll, as well as speed, acceleration, steering and braking commands. This and other data is processed by a computer which instructs hydraulic or pneumatic actuators to override the normal function of 15 resilient springs in order to interpret, compensate and adjust the suspension's performance to suit speed, terrain and other factors in order to maintain a level ride and controlled distribution of weight onto all wheels. These suspension systems require an external intelligent back-up system, and call for substantial input of external energy, drawn from the vehicle engine, to operate the actuators 20 that affect the adjustment to the suspension system.

A range of constructions of 'active' and 'semi-active' suspensions for vehicles have been proposed including systems operating on the basis of compression and/or displacement of fluids and such systems currently in use incorporate a pump to maintain the working fluid at the required 25 pressure and effect the high speed distribution thereof, and sophisticated control mechanisms to regulate the operation of the suspension system in accordance with sensed road and/or vehicle operating conditions. These known systems incorporating pumps and electronic control systems, which are both required to operate substantially continuously while the vehicle is in operation, are

comparatively expensive to construct and maintain, and require energy input, and therefore have limited acceptability in the vehicle industry.

There is disclosed in Australian Patent Application No. 65015/90, a vehicle having a load support body, and a pair of front ground 5 engaging wheels and a pair of rear ground engaging wheels connected to the body to support same, and wherein each wheel is displaceable relative to the body in a generally vertical direction. Interconnected between each wheel and the body is a fluid ram including first and second fluid filled chambers that vary in volume in response to vertical movement between the respective wheels and 10 the body.

The first chambers of the front and rear wheels on each side of the vehicle are in communication by respective individual first fluid circuits. Similarly the second chambers of the front wheels and of the rear wheels are in communication by respective individual second fluid circuits. This construction 15 provides, when the vehicle is in use, substantially the same fluid pressure in the two chambers of any individual fluid circuit thereby inducing all wheels to maintain tractive ground engagement. In practice at least one and preferably each of said individual fluid circuits include at least one pressure accumulator, and preferably also a damping device operable to at least partially dissipate 20 pressure shock in the fluid circuit or circuits.

The vehicle suspension above described differs greatly from all the known systems in that the wheel travel is not dependent upon progressive resilient suspension mechanisms which require variable reactions to the many ever changing conditions experienced by the vehicle. This allows free vertical 25 travel of the individual wheels with respect to the vehicle body or chassis without having to first overcome the resistance of the conventional springing mechanisms normally incorporated between the wheels and the vehicle body. Thus, the wheels are individually unrestrained and free to move to follow the undulations of the surface being travelled without continually changing the 30 vehicle weight distribution between the individual wheels. This reduction or elimination of changes in weight distribution significantly improves the traction

between the wheels and the surface being traversed and the handling characteristics of the vehicle.

A further development of the above described suspension system is disclosed in Australian Patent Application No. 23664/92. In that 5 suspension system a front wheel ram and the diagonally opposite rear wheel ram have the upper chamber of the front ram interconnected with the lower chamber of the rear ram and the lower chamber of the front ram interconnected to the upper chamber of the rear ram. Similarly the respective chambers of the other front ram and rear ram are likewise interconnected. There is thus provided 10 two individual fluid circuits, each comprising a front ram and a diagonally opposite rear ram. Each of the conduits interconnecting the respective upper and lower chambers has a conventional pressure accumulator in communication therewith. The two circuits are interconnected to the load distribution unit arranged to maintain equi-pressure in the two circuits as is 15 described in detail in the previously referred to Australian Patent Application No. 23664/92.

As most vehicles are non-symmetrically loaded for a large portion of the operating time thereof such that loads carried are located so the rear wheels carry more weight than the front wheels, or the load is closer to one 20 side than the other, thus causing the vehicle body to tilt towards the heavier side or end.

It is therefore the object of this invention to provide a vehicle suspension system which determines changes in the vehicular height and inclination and adjusts the fluid in appropriate circuits to reinstate or rectify the 25 optimum relative heights.

With this object in view, there is provided a vehicle suspension system for a vehicle body supported by a plurality of wheels arranged in lateral and longitudinal spaced relation to the vehicle body, including individual fluid ram means arranged between each wheel and the 30 vehicle body, each fluid ram means including a double acting ram having an upper and lower chamber, conduit means individually communicating the upper chamber of the respective rams with the lower chamber of the respective

diagonally opposite ram to provide fluid circuits therebetween, sensor means adapted to generate a signal indicative of the positional relation of each of the wheels relative to the vehicle body, control means arranged to receive said signals and determine the average height of the vehicle body relative to selected 5 pairs of orthogonally adjacent wheels at a selected location between the respective pair of orthogonally adjacent wheels, and adjustment means operable in response to variation of said determined average heights from a respective preset datum height for each said pair of wheels to adjust the quantity 10 of fluid in said circuits communicating with the rams of said orthogonally adjacent wheels to establish said preset datum height between the orthogonally 15 adjacent wheels and the vehicle body at said selected locations.

Preferably the control means is adapted to receive said signals from each said sensor means, and to independently compare the average height of each orthogonally adjacent wheel with the preset datum 15 height of said two wheels. This determination is made in respect of each pair of orthogonally adjacent wheels in sequence, such as front left - front right; rear left - rear right; and then front left - rear left; front right - rear right; and the adjustments are made in a corresponding sequence. This process is repeated until the height of the vehicle body relative to the wheels is at the required 20 respective datum height. The adjustment means is preferably arranged to operate to individually adjust the volume of fluid in the respective fluid circuits connecting the diagonally opposite front and rear wheels to provide the required positional location of the body relative to the wheels.

Conveniently, a said respective sensor means is provided to 25 sense the position of each wheel relative to the vehicle body and provide an input to the control means indicative of that positional relationship. The control means determines from the individual inputs from the sensor means, the average height of the vehicle body between each two orthogonally adjacent wheels and compares this average height with the relevant preset datum height. 30 The preset datum height may be adjustable. For example, the datum height can be adjusted manually or by the control means in dependence on the operational status of the vehicle.

A load distribution means may conveniently be operably interposed between the fluid circuits and adapted to at least substantially equalise the pressure in said fluid circuits and thereby at least substantially equalise the loading on each wheel, the load distribution means having a body 5 supporting at least one displaceable member, the displacement of said displaceable member being a function of the average height of each pair of diagonally opposite wheels, wherein a further sensor means is provided for generating a signal indicative of the positional relation of the at least one displaceable member relative to the body of the load distribution means, the 10 control means being adapted to receive the signal from the further sensor means and to determine and compare the said average height with the position of the displaceable member, the adjustment means adjusting the quantity of fluid in the fluid circuits to return the position of the displaceable member to an optimum position for facilitating the load equalisation on each of the wheels.

15 The body of the load distribution means preferably includes at least two chambers, each chamber supporting a said displaceable member in the form of a piston rod carrying a piston separating the chamber into inner and outer minor chambers, the minor chambers being in fluid communication with opposing said fluid circuits, whereby any pressure differential between the fluid 20 in the minor chambers results in displacement of the piston rod.

The piston rods of each chamber may be operably interconnected to transfer force therebetween. Alternatively, the piston rods may be separately movable, a separate said further sensor means may be provided for each said piston rod to enable the control means to determine the relative 25 position of each piston rod, the outer minor chambers of each chamber may be in fluid communication to enable the adjustment means to adjust the fluid within each said outer minor chamber to thereby control the relative position of the piston rods.

The adjustment means may include pump means and valve 30 means under the control of the control means, for example an ECU, to supply or withdraw fluid from selected fluid circuits to effect the necessary adjustment to

the position of the wheels relative to the vehicle body to achieve the necessary correct average height corresponding to the relevant datum height.

Pressure transducers may be located on at least one of the conduit means and between the pump means and the valve means for providing 5 signals to the control means to thereby prevent any unnecessarily high pressure in the system. This can arise when the vehicle is adjusted for a fully laden vehicle, but the vehicle is actually unladen.

Suspension systems of the general type to which the present invention applies employing fluid actuated rams, conveniently provide in 10 each fluid circuit a pressure accumulator to establish a degree of resilience within the fluid circuit, and hence in the suspension system. Accordingly, as the total weight of the vehicle varies, such as, as a result of adding or removing people or load from the vehicle body, the pressure in the fluid circuits will vary resulting in a variation in the volume of fluid in the accumulator as a 15 consequence of compression of the gas in the accumulator.

Thus, the quantity of the fluid in the accumulator may vary with variations in operating conditions thus, resulting in a variation in the actual amount of fluid in the circuit, excluding the amount of fluid in the accumulator, resulting in a lowering of the body with respect to the wheels. This will result in 20 the signals from the sensor means communicating to the control means a lowering of the average height of the one end and or side of the vehicle body. When such conditions are detected by the control means, the latter initiates operation of the pump means and actuate the appropriate valve means to supply further fluid to that circuit to return the vehicle body to its selected normal 25 operating height. Upon subsequent removal of the additional load, the resulting reduction in pressure in the fluid system will result in the return of fluid from the accumulator to the fluid circuit and necessitate the draining of fluid from the circuit to a reservoir to again establish the nominal correct height of the vehicle body with respect to the wheels. The above discussed departure of the vehicle 30 height from the selected datum can also arise from leakage of fluid from one or more of the fluid circuits, and can be corrected in the manner as above described.

The control means may preferably include a plurality of operational modes, providing differing rates of adjustment in dependence on the variance of the attitude of the vehicle from the preset datum height and the operational status of the vehicle, for example whether the vehicle is in use or is 5 parked. The operational modes may, for example, include "initial set up", "intermediate" and "fine" adjustment cycles whilst the vehicle is in use and a "sleep" mode when it is parked.

Lock out valve means may preferably be located in at least one of the conduit means for selectively preventing flow of fluid therethrough. 10 This "locks out" the resilience in the system or completely prevents ram movement which is desirable under certain circumstances, for example when the handbrake is applied.

It will be convenient to further describe the invention by reference to the accompanying drawings which illustrates possible 15 embodiments of the invention. Other embodiments of the invention are possible and consequently the particularity of the accompanying drawings is not to be understood as superseding the generality of the preceding description of the invention.

In the drawings:

20 Figure 1 is a diagrammatic layout of a vehicle chassis and wheel assembly incorporating the basic suspension system to which the present invention is applicable;

Figure 2 is a fluid circuit diagram of the suspension system shown in Figure 1 incorporating a load distribution unit;

25 Figure 3 is a diagram of a control system for the management of suspension system as shown in Figure 2 by the application of the present invention;

Figure 4 is a fluid circuit diagram of the suspension system incorporating an alternative embodiment of the load distribution unit; and

30 Figure 5 is a schematic diagram showing further details of the control system.

Figures 1 and 2 shows the suspension system discussed in Australian patent application No. 23664/92, details of which are incorporated herein by reference. Referring initially to Figure 1, the vehicle chassis 5, is supported by four wheels 1 to 4 respectively through parallel wishbone type linkage 6, for front wheels 1 and 2 and trailing arms 6a for rear wheels 3 and 4, the construction of each being well known. Other known forms of linkage for connecting vehicle wheels to a chassis could be used if preferred. It is however to be noted that no springs, torsion bars, roll or stabiliser bars or other resilient mechanical suspension elements are necessary between the chassis and the 10 respective wheels.

A respective double acting ram is interconnected between the chassis 5 and the linkages 6 and 6a connecting each wheel to the chassis 5. The front and rear rams on the left side in Figure 1 are numbered 18 and 17 respectively and on the right side 14 and 13 respectively. Each of the rams have 15 a cylinder coupled as at 50 to the chassis 5 and a piston therein dividing the cylinder into two chambers indicated as 17a and 17b in respect of cylinder 17 and 18a and 18b in respect of ram 18. The other two cylinders 13 and 14 are of the same construction and are similarly identified. The piston of each ram is connected to the respective wheel through the linkage 6 so the piston will 20 reciprocate in the cylinder in response to movement in the general vertical direction of the wheel relative to the chassis 5.

The diagonally opposite rams 18 and 14 have the upper chamber 18a and lower chamber 14b in communication by the conduit 10, and lower chamber 18b and upper chamber 14a in communication by the conduit 8. 25 Similarly the upper and lower chambers of the rams 17 and 13 are in communication, chambers 17a and 13b by the conduit 8a and chambers 17b and 13a by conduit 10a.

The conduits 8, 8a, 10 and 10a interconnecting the four double acting rams 13, 14, 17 and 18, which support the chassis 5, each has at 30 least one pressure accumulator 27, 21, 22 and 28 in communication therewith, and are primarily responsible for providing resilience in the suspension as do springs in most prior art sprung suspensions. If the fluid used in the rams and

connecting conduits is compressible, such as a gas, accumulators are not required as the compressible fluid itself provides the required level of resilience. It is preferred, as shown in Figure 2, that additional optional accumulators 23, 24, 29 and 30 are provided in each of the conduits, 8, 10, and 8a, 10a respectively.

5 These accumulators, when provided are preferably smaller and matched in size and close to the lower chambers of the rams thus allowing the fluid in the lower chambers to be expelled quickly and provide resistance to shock loading when the wheels may be thrust down and could damage the pistons and cylinders.

The provision of accumulators in general also enable faster reactions or 10 responses to ram movements, as frictional losses are minimised.

All accumulators preferably are located as near as practical to their associated rams to provide an immediate and accurate response to fast dynamic forces arising when the vehicle is travelling fast.

When the above described suspension is fitted to normally 15 slow moving vehicles, such as cranes, it is appropriate to incorporate only a single accumulator in each conduit, and to locate the accumulator near to the connection of the ram to the conduit. In such vehicles the accumulators may be provided with an isolating means, such as a solenoid valve, to reduce the resilience of these particular circuits when under heavy load. Additionally and 20 conversely there can be multiple accumulators in any circuit and each accumulator may be precharged with gas to a different pressure to provide a progressive range of spring rates to suit different loading situations. The accumulators can each be provided with damping valve in the throat thereof to perform the same function as so called shock absorbers in other vehicles 25 suspension systems.

Flow control devices such as indicated at 31, 32, 33 and 34 in Figure 1 may be provided in any or each of the conduits to reduce the rate of the fluid flow to ensure that the rams at either end of the conduits communicate directly at a relatively slow speed, as arises when the vehicle is traversing rough 30 ground requiring large wheel travel motions, and optimum low ground pressure on all wheels. At high speeds the small dynamic wheel travel motions are best resolved primarily by the accumulators.

Any of the conduits may be provided with flow control devices of a variable nature or other means to vary and even stop the flow along the conduits between the connected rams. An example of such a valve may be a solenoid valve controlled by an ECU which processes a variety of information 5 from sources such as accelerometers or pressure transducers and thereby cause the sudden or gradual closure of the valves.

The above construction of the suspension system results in the movement of wheels 1 and 3, relative to the chassis 5, under the control of double acting rams 18 and 14, being in the same direction due to the 10 arrangement of the interconnecting conduits 8 and 10. The movements are also approximately equal except for such difference as may arise from the fluid passed to the accumulator or accumulators coupled to the conduits 8 and 10. The same conditions exist in respect of the wheels 4 and 3.

The above interactions between the respective rams 15 associated with each wheel of the vehicle effects control of roll when the vehicle is turning; particularly when turning at speed, and control of pitch when the vehicle is braking or acceleration, particularly severe braking or acceleration.

The suspension system shown in Figure 1 is illustrated diagrammatically in Figure 2 and in addition incorporates a load distribution unit 20 40 with which each of the conduits 8, 8a, 10 and 10a are in direct independent communication. The load distribution unit 40 comprises a body 41 having in one embodiment a cylindrical bore 42 closed at each end 43 and 44 and divided into two major chambers 46 and 47 by the intermediate fixed wall 45. Respective pistons 48 and 49 are provided in the major chambers 46 and 47 respectively 25 each mounted on the common piston rod 51 which extends in sealed relation through the intermediate wall 45 and each closed ends 43 and 44 of the body 41. This arrangement results in each side of the respective pistons having the same area.

The pistons 48 and 49 and the piston rod 51 can move in the 30 cylindrical bore 42 providing four variable volume minor chamber 55, 56, 57 and 58, with minor chambers 55 and 57 varying in the same direction in response to piston movement, and minor chambers 56 and 58 varying in the same direction

but in the opposite direction to minor chamber 55 and 57 for the same piston movement. The conduits 8 and 10, forming the fluid circuit between diagonally opposite fluid rams 18 and 14, communicate with minor chamber 55 and 57 by branch conduits 60 and 61. Similarly conduits 8a and 10a, forming the fluid circuit between diagonally opposite rams 17 and 13, communicate with minor chambers 56 and 58 by branch conduits 62 and 63.

In the initial setting up of the suspension the fluid in the chambers 55, 56, 57 and 58 are adjusted so that the pistons 48 and 49 are each located substantially centrally in the respective major chambers 47 and 46 with 10 the pressure in each chamber equal.

When operating the vehicle, if the net pressure in minor chambers 55 and 57 is greater than the net pressure in minor chambers 56 and 58 a force will exist to effect displacement of the pistons 48 and 49 upwardly as seen in Figure 2 to achieve a balance between the respective net pressures. 15 This in turn will displace fluid from chambers 56 and 58 into the respective conduits 8a and 10a to bring about a balanced pressure in all of the double acting fluid rams 13, 14, 17 and 18 thereby achieving substantially uniform load distribution between all four wheels 1, 2, 3 and 4, independent of the respective position of each wheel relative to the chassis 5.

20 This pressure balance between the fluid in the respective circuits is important to achieve when variation in wheel positions is relatively large as encountered in traversing terrain of substantial irregular surface, such as encountered in off-road vehicle operation, and where wheel movement is of relatively lower frequency but of substantial magnitude. In such operating 25 conditions, it is most desirable to retain substantially even load distribution to all wheels in order to maintain traction and prevent bogging of the vehicle. Also in such conditions it is important to reduce lateral tilting of the vehicle to improve driver and passenger comfort, and safety from rolling over of the vehicle. The load distribution unit 40 operable as above discussed affects the necessary 30 transfer of fluid to maintain substantial even load distribution between all four wheels and reduced chassis tilting movement.

Although the present invention is applicable directly to the suspension system disclosed in Australian application No. 23664/92 as shown in Figures 1 and 2, it is however also applicable to suspension systems of alternative constructions.

5 Referring now to Figure 3 of the drawings, there is illustrated therein the suspension system shown in and described with reference to Figures 1 and 2, modified to incorporate the present invention. In Figure 3, the same reference numerals are used for components corresponding to those shown in Figures 1 and 2. The additional components comprise wheel position sensors 10 360, 361, 362 and 363 associated with wheels 1, 2, 3 and 4 respectively and arranged to generate respective signals indicative of the position of the wheel relative to the vehicle body 5. Also there is provided a centrally positioned sensor 364 to sense the position of the piston rod 51 relative to the body 41 of the load distribution unit 40. In addition there is provided a pump 65, a fluid 15 reservoir 66, a bank of valves 67 and an electronic control unit (ECU) 68.

The bank of valves 67 control the supply of fluid by the pump 65 to the respective conduits 8, 8a, 10 and 10a and the return of fluid from the conduits to the reservoir 66. The individual valves of the valve bank 67 are controlled by the ECU 68 in response to signals from the position sensors 360, 20 361, 362, 363 and 364 as hereinafter described. The valves of the valve bank 67 can be activated to couple the pump 65 to any one or a number of the conduits and also one or a number of the conduits to the reservoir 66.

The ECU 68 is programmed to receive respective signals from the wheel position sensors 360, 361, 362 and 363 and determine the 25 average height of the vehicle body 5 between selected pairs of orthogonally adjacent wheels. The average height between every pair of orthogonally adjacent wheels, that is the average height between wheels 1-2, 2-3, 3-4 and 4-1, can be determined. It is also possible to limit the determination of the average height to only between selected pairs of orthogonally adjacent wheels. The 30 ECU 68 is further programmed to compare each determined average height with a respective pre-selected 'desired' for each wheel pair height. If the determined average height differs from the pre-selected desired average height beyond a